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13. ABSTRACT (Maximum 200 words) High Cycle Fatigue (HCF) is a fundamental weakness in the technology base for turbine engines. To avoid surprise HCF failures or to design blades for longer life, accurate vibratory stress predictions are crucial. This requires validated design systems. As multistage blade row interactions drive most HCF problems, the key barrier research issue is MultiStage Interaction Steady and Unsteady Aerodynamics. Hence, multistage forcing functions, their mutual interaction, and the resultant blade row steady and unsteady aerodynamic response, including three-dimensional and transonic flow conditions, must be addressed. To validate or direct the development of advanced models and the complete aeroelastic design system, data obtained in an appropriate multistage flow environment are required. Of particular interest is defining these three-dimensional blade row flow fields with enough detail for use in CFD code verification and development, thereby enabling the limits of applicability and the modeling inherent in the various codes to be addressed. To accomplish this, first appropriate experimental facilities which experimentally model the fundamental three dimensional steady and unsteady flow phenomena are required. These are either currently available or are in progress funded by AFOSR at Purdue University. Hence, the key experimental issue is nonintrusive instrumentation capable of three-dimensional whole flow field measurements. Under this grant, instrumentation has been acquired to be utilized to quantify the three-dimensional blade row steady and instantaneous blade-to-blade velocity field.					
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## **FINAL REPORT**

### **A PROPOSAL FOR EQUIPMENT FOR INTELLIGENT AEROELASTIC SYSTEMS: Advanced Instrumentation For Unsteady Aerodynamics & Aeromechanics Of Multi-Stage Turbomachinery Blading**

Submitted to

Department of the Air Force  
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## INTRODUCTION

High Cycle Fatigue (HCF) is a fundamental weakness in the technology base for turbine engines. To avoid surprise HCF failures or to design blades for longer life, accurate vibratory stress predictions are crucial. This requires validated design systems. As multistage blade row interactions drive most HCF problems, the key barrier research issue is MultiStage Interaction Steady and Unsteady Aerodynamics. Hence, multistage forcing functions, their mutual interaction, and the resultant blade row steady and unsteady aerodynamic response, including three-dimensional and transonic flow conditions, must be addressed.

Currently only conventional data are obtained in engines, rigs or isolated rotors, with detailed two-dimensional data typically available primarily in low speed rigs, typically at the design point. Thus, to validate or direct the development of advanced models and the complete aeroelastic design system, data obtained in an appropriate multistage flow environment are required. These data must completely and accurately define the steady and unsteady three-dimensional flow field. Of particular interest is defining these three-dimensional blade row flow fields with enough detail for use in CFD code verification and development, thereby enabling the limits of applicability and the modeling inherent in the various codes to be addressed.

To accomplish this, first appropriate experimental facilities which experimentally model the fundamental three dimensional steady and unsteady flow phenomena are required. These are either currently available or are in progress funded by AFOSR at Purdue University. Hence, the key experimental issue is nonintrusive instrumentation capable of three-dimensional whole flow field measurements. Under this grant, instrumentation has been acquired to be utilized to quantify the three-dimensional blade row steady and instantaneous blade-to-blade velocity field.

## INSTRUMENTATION PURCHASED

A summary of expenditures on the grant is as follows:

1)	SPIV system from Dantec Electronics	\$289,875.
2)	Optics Position Controllers	39,790.
3)	Control Computers	9,165.
4)	Nd-Yag Laser for PIV	8,445.
5)	External Data Storage	1,096.
6)	Cross-Correlation PIV Digital Cameras	40,271.
<b>Total Expenditures:</b>		<hr/> \$388,642.

Item 1 consists of a Dantek Particle Image Velocimetry (PIV) system PIV system with processors units allowing both two dimensional (on-axis) and three dimensional (off-axis stereo-

PIV) data to be acquired simultaneously. Item 2 consists of a nano-positioning system to handle the two required digital imaging cameras for SPIV. Item 3 consists of computers that interface with the PIV processor mainframes. Item 4 is the partial cost of a Nd-Yag laser for PIV imaging (other funds were used to complete the purchase). Item 5 consist of external tape storage for the large volumes of data obtained. Item 6 consists of dual cross-correlations type digital cameras for SPIV and PIV investigations. The total amount of the expenditures includes \$97,161 in Purdue University cost sharing funds. In the original proposal, a telemetry system had been proposed. Since we were able to obtain a system from other sources, the funds from this grant were directed exclusively to tools to implement the optical diagnostic portion of the proposal.

### **REPRESENTATIVE APPLICATIONS**

The instrumentation purchased above has been used to characterize the forcing function generated by blade row interactions in transonic compressor blading. This research has been undertaken as part of an AFOSR program (Unsteady Aerodynamics & Aeromechanics Of MultiStage Turbomachinery Blading) and performed on the Purdue High Speed Axial Compressor research facility. Under this program, the high unsteady loading generated by a transonic rotor has been demonstrated. Figure 1 presents PIV data from the facility IGV (inlet guide vane). The rotor shock structure propagates upstream into the IGV and generates a large excitation to blade vibration which will lead to ultimate HCF failure when operated near a blade resonant mode. The complete flow field in the upstream and downstream blade row has been characterized with two-dimensional PIV, achieving unique data that are suited for comparison with, and calibration of, state-of-the-art design systems. Work on this facility is now progressing to the rotor flow field.

In preparation for stereo-PIV (SPIV) measurements on high speed facilities, experiments have been conducted in our low speed turbine research facility to provide a benign development environment for this advanced technique. The first experiments were tailored toward the seal purge flow effects on the downstream rotor aerodynamics. These provided experiments with severe off-axis imaging, which is an essential part of a SPIV setup. Two-dimensional data showed a substantial impact on rotor aerodynamics caused by an interaction of the seal flow with both the rotor potential forcing function and the wakes from upstream vanes. Actual 3-D SPIV data is now being acquired in the rotor tip region of this facility, with the setup showing the two off-axis imaging cameras presented in Figure 3.

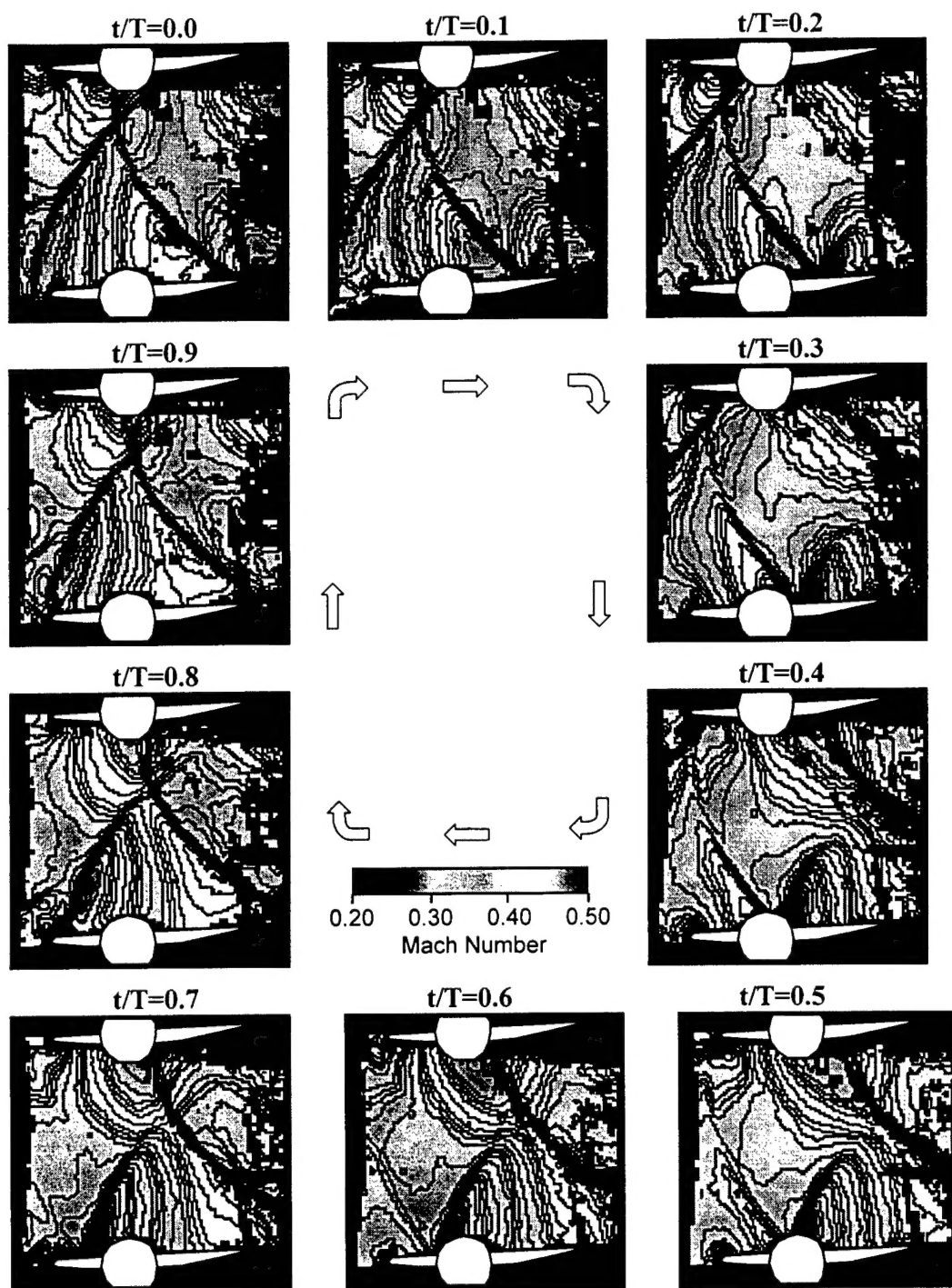


Figure 1: Time-Variant IGV velocity field generated by a downstream transonic rotor. Interaction with the rotor shock results in very high unsteady loading on the upstream guide vane.

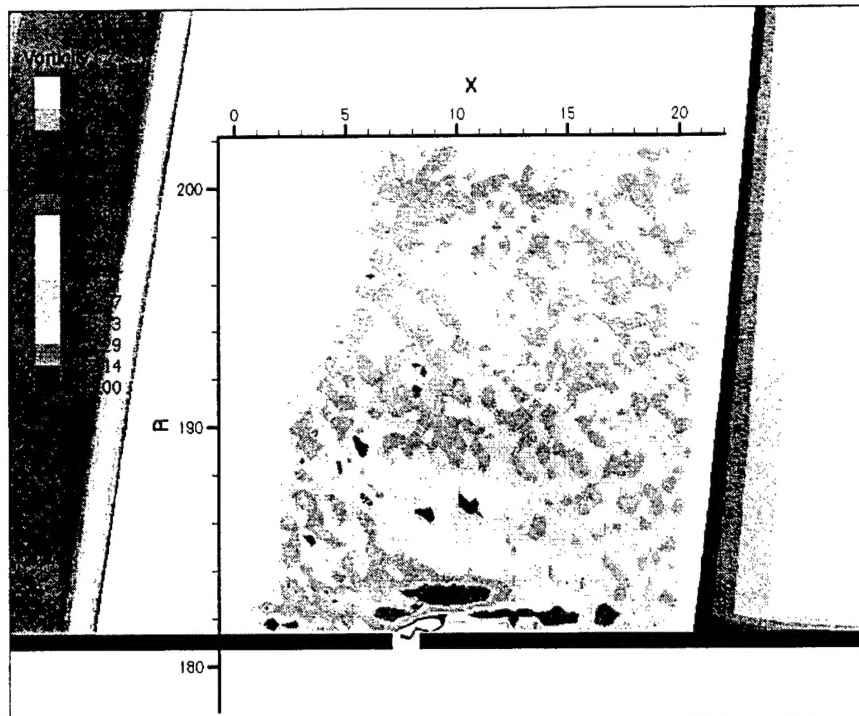


Figure 2: Characterization of a seal purge flow emerging from a turbine stage (scale in mm). The seal purge flow is highly dependent on the nature of the unsteady forcing function generated by the blade potential field and vane wakes.

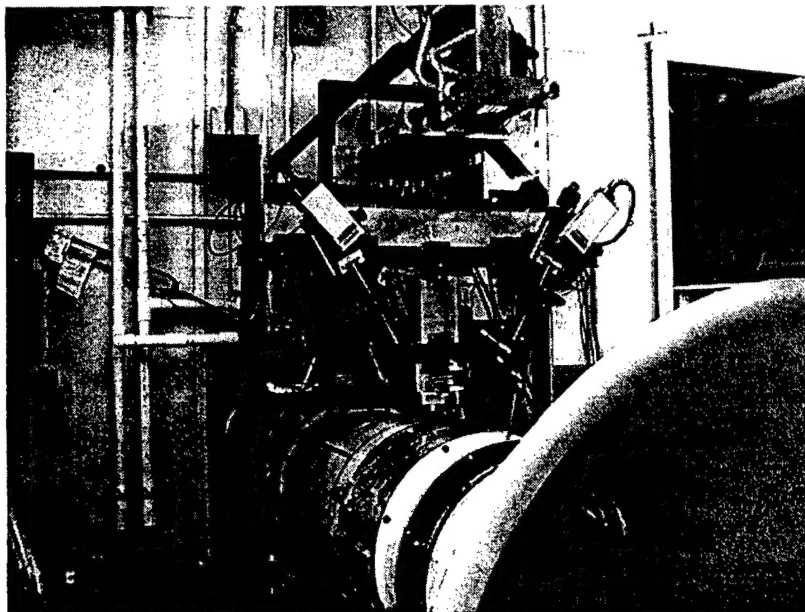


Figure 3. Stereo PIV imaging set up on low speed turbine facility.